

Chapter 7 Structural Design Considerations

7-1. Introduction

This chapter discusses the layout, design, and construction considerations associated with concrete gravity dams. These general considerations include contraction and construction joints, waterstops, spillways, outlet works, and galleries. Similar considerations related to RCC gravity dams are addressed in Chapter 9.

7-2. Contraction and Construction Joints

a. To control the formation of cracks in mass concrete, vertical transverse contraction (monolith) joints will generally be spaced uniformly across the axis of the dam about 50 feet apart. Where a powerhouse forms an integral part of a dam and the spacing of the units is in excess of this dimension, it will be necessary to increase the joint spacing in the intake block to match the spacing of the joints in the powerhouse. In the spillway section, gate and pier size and other requirements are factors in the determination of the spacing of the contraction joints. The location and spacing of contraction joints should be governed by the physical features of the damsite, details of the appurtenant structures, results of temperature studies, placement rates and methods, and the probable concrete mixing plant capacity. Abrupt discontinuities along the dam profile, material changes, defects in the foundation, and the location of features such as outlet works and penstock will also influence joint location. In addition, the results of thermal studies will provide limitations on monolith joint spacing for assurance against cracking from excessive temperature-induced strains. The joints are vertical and normal to the axis, and they extend continuously through the dam section. The joints are constructed so that bonding does not exist between adjacent monoliths to assure freedom of volumetric change of individual monoliths. Reinforcing should not extend through a contraction joint. At the dam faces, the joints are chamfered above minimum pool level for appearance and for minimizing spalling. The monoliths are numbered, generally sequentially, from the right abutment.

b. Horizontal or nearly horizontal construction joints (lift joints) will be spaced to divide the structure into convenient working units and to control construction procedure for the purpose of regulating temperature changes. A typical lift will usually be 5 feet consisting of three 20-inch layers, or 7-1/2 feet consisting of five 18-inch layers. Where necessary as a temperature control

measure, lift thickness may be limited to 2-1/2 feet in certain areas of the dam. The best lift height for each project will be determined from concrete production capabilities and placing methods. EM 1110-2-2000 provides guidance on establishing lift thickness.

7-3. Waterstops

A double line of waterstops should be provided near the upstream face at all contraction joints. The waterstops should be grouted 18 to 24 inches into the foundation or sealed to the cutoff system and should terminate near the top of the dam. For gated spillway sections, the tops of the waterstops should terminate near the crest of the ogee. A 6- to 8-inch-diameter formed drain will generally be provided between the two waterstops. In the nonoverflow monolith joints, the drains extend from maximum pool elevation and terminate at about the level of, and drain into, the gutter in the grouting and drainage gallery. In the spillway monolith joints, the drains extend from the gate sill to the gallery. A single line of waterstops should be placed around all galleries and other openings crossing monolith joints. EM 1110-2-2102 provides further details and guidance for the selection and use of waterstops and other joint materials.

7-4. Spillway

a. The primary function of a spillway is to release surplus water from reservoirs and to safely bypass the design flood downstream in order to prevent overtopping and possible failure of the dam. Spillways are classified as controlled (gate) or uncontrolled (ungated). The overflow (ogee) spillway is the type usually associated with concrete gravity dams. Other less common spillway types such as chute, side channel, morning glory, and tunnel are not addressed in this manual.

b. An overflow spillway profile is governed in its upper portions by hydraulic considerations rather than by stability requirements. The downstream face of the spillway section terminates either in a stilling basin apron or in a bucket type energy dissipator, depending largely upon the nature of the site and upon the tailwater conditions. The design of the spillway shall include the stability and internal stress analysis and the structural performance. Loadings should be consistent with those discussed in Chapter 4. Operating equipment should be designed to be operational following a maximum credible earthquake.

c. Discharge over the spillway or flip bucket section must be confined by sidewalls on either side, terminating in training walls extending along each side of the stilling

basin or flip bucket. Height and length of training walls are usually determined by model tests or from previous tests of similar structures. Sidewalls should be of sufficient height to contain the spillway design flow, with a 2-foot freeboard. Negative pressures (see EM 1110-2-1603) due to flowing water should be considered in the design of the sidewalls, with the maximum allowance (see EM 1110-2-2400) being made at the stilling basin, decreasing uniformly to no allowance at the crest. Sidewalls are usually designed as cantilevers projecting out of the monolith. A wind load of 30 pounds/square foot or earthquake loading should be assumed for design of reinforcing in the outer face of the walls. The spillway section surfaces should be designed to withstand the high flow velocities expected during peak discharge and reduced pressures resulting from the hydrodynamic effects.

d. The dynamic loads occurring in the energy dissipators will include direct impact, pulsating loads from turbulence, multidirectional and deflected hydraulic flows, surface erosion from high velocities and debris, and cavitation. The downstream end of the dissipator should include adequate protection against undermining from turbulence and eddies. Concrete apron, riprap, or other measures have been used for stabilization.

7-5. Spillway Bridge

a. Bridges are provided across dam spillways to furnish a means of access for pedestrian and vehicular traffic between the nonoverflow sections; to provide access or support for the operating machinery for the crest gates; or, usually, to serve both purposes. In the case of an uncontrolled spillway and in the absence of vehicular traffic, access between the nonoverflow sections may be provided by a small access bridge or by stair shafts and a gallery beneath the spillway crest.

b. The design of a deck-type, multiple-span spillway bridge should generally conform to the following criteria. The class of highway design loading will normally not be less than HS-20. Special loadings required for performing operation and maintenance functions and those that the bridge is subjected to during construction should be taken into account, including provisions for any heavy concentrated loads. Heavy loadings for consideration should include those due to powerhouse equipment transported during construction, mobile cranes used for maintenance, and gantry cranes used to operate the regulating outlet works and to install spillway stoplogs. If the structure carries a state or county highway, the design will usually

conform to the standard specification for highway bridges adopted by the American Association of State Highway and Transportation Officials (AASHTO).

c. Materials used in the design and construction of the bridge should be selected on the basis of life cycle costs and functional requirements. Floors, curbs, and parapets should be reinforced concrete. Beams and girders may be structural steel, precast or cast-in-place reinforced concrete, or prestressed concrete. Prestressed concrete is often used because it combines economy, simple erection procedures, and low maintenance.

7-6. Spillway Piers

a. For uncontrolled spillways, the piers function as supports for the bridge. On controlled spillways, the piers will also contain the anchorage or slots for the crest gates and may support fixed hoists for the gates. The piers are generally located in the middle of the monolith, and the width of pier is usually determined by the size of the gates, with the average width being between 8 and 10 feet. The spillway piers in RCC dams are constructed with conventional concrete.

b. Since each pier supports a gate on each side, the following pier loading conditions should be investigated:

(1) Case 1--both gates closed and water at the top of gates.

(2) Case 2--one gate closed and the other gate wide open with water at the top of the closed gate.

(3) Case 3--one gate closed and the other open with bulkheads in place and water at the top of the closed gate.

c. Cases 1 and 3 result in maximum horizontal shear normal to the axis of the dam and the largest overturning moment in the downstream direction.

d. Case 2 results in lower horizontal shear and downstream overturning moment, but in addition the pier will have a lateral bending moment due to the water flowing through the open gate and to the hoisting machinery when lifting a closed gate. A torsional shear in the horizontal plane will also be introduced by the reaction of the closed gate acting on one side of the pier. When tainter gates with inclined end frames are used, Cases 2 and 3 introduce the condition of the lateral component of the thrust on the trunion as a load on only one side of the pier in addition to the applicable loads indicated above.

7-7. Outlet Works

a. The outlet works for concrete dams are usually conduits or sluices through the mass with an intake structure on the upstream face, gates or valves for regulation control, and an energy dissipator on the downstream face. Multiple conduits are normally provided because of economics and operating flexibility in controlling a wide range of releases. The conduits are frequently located in the center line of the overflow monoliths and discharge into the spillway stilling basin. Outlet works located in nonoverflow monoliths will require a separate energy dissipator. All conduits may be at low level, or some may be located at one or more higher levels to reduce the head on the gates, to allow for future reservoir silting, or to control downstream water quality and temperature. The layout, size, and shape of the outlet works are based on hydraulic and hydrology requirements, regulation plans, economics, site conditions, operation and maintenance needs, and interrelationship to the construction plan and other appurtenant structures. Conduits may be provided for reservoir evacuation, regulation of flows for flood control, emergency drawdown, navigation, environmental (fish), irrigation, water supply, maintaining minimum downstream flows and water quality, or for multiple purposes. Low-level conduits are used to aid water quality reservoir evacuation and are sometimes desirable for passage of sediment. These openings are generally unlined except for short sections adjacent to the control gates. For lined conduits, it is assumed that the liner is designed for the full loading. In conduits where velocities will be 40 feet/second or higher, precautions will be taken to ensure that the concrete in the sidewalls and inverts will be of superior quality. If the dam includes a power intake section, penstocks will be provided and designed in accordance with EM 1110-2-3001.

b. The effect of project functions upon outlet works design and hydraulic design features, including trashrack design and types for sluice outlets, are discussed in EM 1110-2-1602. A discussion of the structural features of design for penstocks and trashracks for power plant intakes is included in EM 1110-2-3001. The structural design of outlet works is addressed in EM 1110-2-2400.

7-8. Foundation Grouting and Drainage

It is good engineering practice to grout and drain the foundation rock of gravity dams. A well-planned and executed grouting program should assist in disclosing weaknesses in the foundation and improving any existing defects. The program should include area grouting for foundation treatment and curtain grouting near the

upstream face for seepage cutoff through the foundation. Area grouting is generally done before concrete placement. Curtain grouting is commonly done after concrete has been placed to a considerable height or even after the structure has been completed. A line of drainage holes is drilled a few feet downstream from the grout curtain to collect seepage and reduce uplift across the base. Detailed information on technical criteria and guidance on foundation grouting is contained in EM 1110-2-3506.

7-9. Galleries

A system of galleries, adits, chambers, and shafts is usually provided within the body of the dam to furnish means of access and space for drilling and grouting and for installation, operation, and maintenance of the accessories and the utilities in the dam. The primary considerations in the arrangement of the required openings within the dam are their functional usefulness and efficiency and their location with respect to maintaining the structural integrity.

a. Grouting and drainage gallery. A gallery for grouting the foundation cutoff will extend the full length of the dam. It will also serve as a collection main for seepage from foundation drainage holes and the interior drainage holes. The location of the gallery should be near the upstream face and as near the rock surface as feasible to provide the maximum reduction in overall uplift. A minimum distance of 5 feet should be maintained between the foundation surface and gallery floor and between the upstream face and the gallery upstream wall. It has been standard practice to provide grouting galleries 5 feet wide by 7 feet high. Experience indicates that these dimensions should be increased to facilitate drilling and grouting operations. Where practicable, the width should be increased to 6 or 8 feet and the height to 8 feet. A gutter may be located along the upstream wall of the gallery where the line of grout holes is situated to carry away drill water and cuttings. A gutter should be located along the downstream gallery wall to carry away flows from the drain pipes. The gallery is usually arranged as a series of horizontal runs and stair flights. The stairs should be provided with safety treads or a nonslip aggregate finish. Metal treads are preferable where it is probable that equipment will be skidded up or down the steps since they provide protection against chipping of concrete. Where practicable, the width of tread and height of riser should be uniform throughout all flights of stairs and should never change in any one flight. Further details on the grouting and drainage gallery are covered in EM 1110-2-3506.

b. Gate chambers and access galleries. Gate chambers are located directly over the service and emergency sluice gates. These chambers should be sized to accommodate the gate hoists along with related mechanical and electrical equipment and should provide adequate clearances for maintenance. Access galleries should be sufficient size to permit passage of the largest component of the gates and hoists and equipment required for maintenance. Drainage gutters should be provided and the floor of the gallery sloped to the gutter with about 1/4 inch/foot slope.

7-10. Instrumentation

Structural behavior instrumentation programs are provided for concrete gravity dams to measure the structural

integrity of the structure, check design assumptions, and monitor the behavior of the foundation and dam during construction and the various operating phases. The extent of instrumentation at projects will vary between projects depending on particular site conditions, the size of the dam, and needs for monitoring critical sections. Instrumentation can be grouped into those that either directly or indirectly measure conditions related to the safety of the structure. Plumbing, alignment, uplift, and seismic instruments fall into the category of safety instruments. In the other group, the instruments measure quantities such as stress and strain, length change, pore pressure, leakage, and temperature change. Details and guidance on the planning of instrumentation programs, types of instruments, and the preparation, installation, and collection of data are provided in EM 1110-2-4300.